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The Effects of Mental Practice on Strength Gain and Electromyographic Changes in Elbow Flexor Muscles

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ABSTRACT

The purpose of the present research was to study the effects of mental practice on the strength gain and electromyographic changes in elbow flexor muscles. 16 healthy, non-athlete men with 22.5±1.36 years of age, 175.18±6.62 cm of height, 68.78±7.05 kg of wei ght, and 20.81±3.71 motor imagery ability without any record of injury in elbow, shoulder, wrist, and elbow tendons and flexor muscles were selected and randomly divided into an experimental group (8 subjects) and a control group (8 subjects). The experimental group imagined maximum voluntary contractions of the elbow flexors for four weeks and five sessions a week. The control group did not participate in any physical or mental practice, but they were included in all the measurements. The exercise program involved the imagery of 50 maximum voluntary contractions in two rounds with 25 repetitions. The maximum voluntary contraction (MVC) and integrated electromyography (IEMG) were measured during maximum voluntary contractions of the elbow flexor muscle group in the pretest and the posttest. Student's t-test was applied for data analysis at $P \leq 0.05$ *significance level. The results revealed that the strength of elbow flexor muscles increased by 30% in the experimental group and5% in the control group and a significant difference was observed between the experimental group and the control group in the strength gain of elbow flexor muscles. Moreover, integrated electromyography increased significantly in the elbow flexor muscles of the experimental group and decreased significantly in elbow extensor muscles. The overall results of the research suggested that mental practice can increase the strength of elbow flexor muscles and this strength gain is apparently associated with the changes in the programming of the central nervous system which has led to an increase in the level of activation of agonist muscles.*

Keywords: mental practice, strength, electromyography, maximum voluntary contraction.

INTRODUCTION

The increase in voluntary muscle strength is due to neural adaptation and muscle hypertrophy and the strength gain at the early levels of exercise program is mainly due to changes in the nervous system [1, 2]. In fact, physical exercise causes adaptation in the brain and spinal cord; as a result, the ability of the individual to recruit motor units increases and this will facilitate muscle contraction and will increase muscles' ability to generate power [15, 2]. In addition, research studies have shown that exercising the muscles of a limb is followed by an increase in the strength of the antagonist muscles without any exercise [14]. When the arm muscles on one side of the body were subjected to endurance training, part of the effect of the exercise was transferred to the arm muscles of the contralateral part of the body. In this case the strength gain in the exercised arm is related to muscle hypertrophy and the increased activation of motor units; yet, strength gain in the untrained arm is due to neural adaptation [11]. The phenomenon of strength gain in the untrained muscle has led to the belief that muscle strength can increase without repeated activation of the muscle or motor neurons [14], while this issue was not widely studied in clinically and scientifically oriented research. Early strength gain may be due to changes in the motor program of maximum voluntary contraction of the muscle in the central nervous system; thus, changes may occur in the motor program for maximum voluntary contraction as a result of mental practice [22].

On the other hand, research on skill acquisition showed that mental practice leads to better performance. Until a few years ago, scientists studying skill acquisition were uncertain that mental practice leads to learning. At that time, the existing notion of practice and acquisition had made physical practice an indispensable part of learning and it was apparently difficult to understand how learning may occur without performing movements or without active exercise. Nonetheless, various studies yielded satisfying evidence suggesting that mental practice processes really lead to motor learning. Thus, neural factors which control muscle parameters (amplitude-timing) can improve by mental practice. This interpretation was supported by research evidence that during motor learning, neural activities in different brain regions change based on the level of motor skill achievement [12, 10]. It is therefore possible that repeated imagery of contractions will change the maximum energy production in a joint. These changes in the programming of the central nervous system may increase the activation of motor neurons or increase the relative levels of activation of agonist and antagonist muscles in a joint [22]. Finally, considering the strength gain in the early stages of exercise due to neural adaptations, the phenomenon of increase in muscle strength of the contralateral limb, and improvement of motor skill performance with mental practice, the question that arises is whether imagery of maximum voluntary muscle contractions can increase the strength of the proximal muscle group including elbow flexor muscles.

The goal of advanced medical programs for neurological and orthopedic diseases is to increase the strength of muscles or specific muscle groups. Techniques implemented by physiotherapists for improving strength include strength training with weights, elastic bands, isokinetic and isotonic machines, and electrical neuromuscular simulation. In most of these techniques, the patient needs muscle contraction for exercise and since in some orthopedic and neurological injuries muscle contraction is painful or even impossible, neurological research suggest that it is possible to improve strength through mental practice without the need for muscle contraction

[16]. In a research aiming to increase the strength of the abductor muscle of little finger, Yue showed that mental practice has increased strength up to 22%. However, the effect of mental practice on the strength of the proximal muscles that are mostly used in everyday activities has not yet been specified [22]. In 1998, Herbert found no significant difference between the control group and the mental practice group in the changes in the strength of elbow flexor muscles [5] and Ranganathan (2004) came to a similar conclusion [14]. It appears that these research studies have disregarded internal imagery and imagery ability which are two of the factors that play an important role in the success of mental practice. Studies have shown that the efficiency of imagery as a form of mental practice depends on the imagery ability of the individual. Some people can hardly form a mental image of an action while others can do so with great vividness and control; it is thus illogical to expect an individual with poor imagery ability in a mental practice group to have a better control in comparison with other group participants [17, 6]. Therefore, by taking into account the imagery ability of subjects and by using internal imagery, the present research studies the effects of mental imagery on strength gain and electromyography changes in elbow flexor muscles.

MATERIALS AND METHODS

Subjects

The subjects were 16 healthy, untrained male students, right-handed, with 22.5±1.36 years of age, 175.18±6.62 cm of height, 68.78±7.05 kg of weight, and 20.81±3.71 motor imagery ability. Prior to carrying out the research, the subjects filled out the Sports Medicine Questionnaire, Motor Imagery Ability Questionnaire, and the forms of consent. The subjects had no record of regular endurance training, nor did they have any record of other regular sports exercise over the past two years; they had no record of ailment or surgery in upper limb muscles and were purposefully selected and were randomly divided into the mental practice group (8 subjects) and the control group (8 subjects) using simple random selection method; the pretest and posttest measurements were repeated after four weeks of practice [14, 22].

Practice Program

The subjects in the experimental group performed mental contractions of elbow flexor muscles for 4 weeks, 5 sessions a week, and 50 contractions in each session. The subjects in the control group had no physical exercise but participated in all the measurements. Further, the subjects were asked to immediately inform the researcher about any change in their lifestyles and daily activities [14]. During practice sessions, subjects sat on a chair with their arms hanging at the side of their body without any tension. The subjects were asked to close their eyes, take a deep breath, and relax all their body for 2 minutes. Then, by the order of the trainer, the subjects mentally generated, in the form of internal imagery, the maximum contraction they had produced in the pretest for measuring the strength of elbow flexor muscles. After 5 seconds of contraction and by researcher's order to rest, the subjects rested for 5 seconds. This mental contraction was alternately repeated 25 times; afterwards the subjects rested for two minutes and then performed another 25 mental contractions. The arm muscles of the subjects were obviously without any voluntary tension or contraction during the practice and this issue was controlled by the researcher during the entire mental practice session. Moreover, during the period of mental practice, the heart rate of one of the subjects was randomly measured and recorded each week during both resting and performing mental practice using a digital pulse-meter [14].

Measuring Static Strength

Measuring the MVC of the right hand of each subject in the control group and the experimental group was repeated three times with a 2-minute rest interval between each measurement and the maximum value obtained was used for data analysis [14]. The elbow flexion force was measured by means of a load cell set between the lever and the base which were connected by a cable; the force signal was transferred from the load cell to a DC amplifier (Jackson 33528, Lafayette Inc., USA) and was displayed using the oscilloscope of the device. Thus, the subject sat on the seat of the device and in order to prevent him from using other muscles, his trunk was completely fastened and fixed by a belt, the shoulder joint was positioned in 90° abduction so that the arm was along the shoulder, and the knee angle was fixed and measured at 90° (figure 1) using an SG110 goniometer made by Biometrics Inc., England [20].During measurement, the subject was asked to gradually exert his maximum force in two seconds and to maintain the maximum force for three seconds after reaching it. Indeed the subjects were verbally encouraged to achieve maximum strength during the test, and to increase the motivation of the subjects, they were told that a prize would be given to the one with the highest recorded force [14].

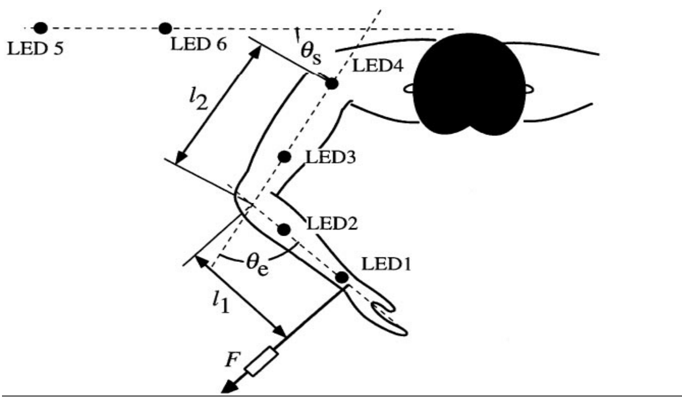

Figure 1. Knee and shoulder angles

(in this state, the subject is in a position where he can only use his elbow flexor muscles for exerting force)

Recording Electromyography (EMG):

Bipolar electrodes (two active electrodes and one ground electrode) were used to record EMG by means of an eight-channel Muscle Tester ME3000p8 made by Mega Electronic Inc., Finland. To decrease the electrical impedance at the skin-electrode interface, first the extra skin hair was removed; then, the skin was rubbed with a fine abrasive in a smooth and controlled fashion, and afterwards it was cleaned using a piece of cotton smeared with alcohol. The criterion for reaching a favorable level of skin impedance (low resistance) was for the skin to turn into a light red color. Then, a Medicotest Blue Sensor wet Ag gel was applied. The space between the two electrodes was 2 cm and their location was marked by a magic marker at the mid-belly of biceps brachii, brachioradialis, and triceps brachii based on the schematic instructions of Mega Win software (Ver. 2); then, the electrodes were connected to the points of interest (figure 2) [14, 8]. To decrease the noise, other electric devices were kept away from the measurement device and the room temperature was fixed (at 25 degrees centigrade) as much as possible. During the MVC test for measuring EMG, the sound alarm of the EMG system was used as an indication of the beginning and the end of contraction. The EMG signal from electrodes was amplified using a preamplifier (Megawin; Mega Electronic, Finland) with a band pass of 8Hz (high pass) to 500Hz (low pass). Then, sampling was done using a 12-bit 8-channel analog-to-digital (A/D) converter with 3 mV sensitivity and 2.95 mV resolution (110db type) made by the same factory and the samples were transferred to a computer using an optical cable.

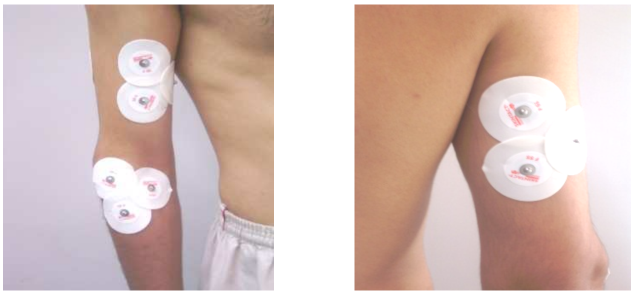

Figure 2 . The location of electrodes at the mid-belly biceps brachii, brachioradialis, and triceps brachii

Signal Processing
Megawin 2 software designed by Mega Electronic Inc. was used for signal processing and computing IEMG. IMEG was measured in a 3-second time interval using the *Markers* of the related software.

Analysis
T-test was applied for data analysis and for comparing the studied variables in both experimental and control groups; the resting heart rate and the heart rate during mental practice were also compared using correlated t-test. Data analysis was done at $P \leq 0.05$ significance level and in SPSS 11.5 software [3].

RESULTS

The MVC data of elbow flexor muscles as well as the mean IEMG of elbow flexor muscles and triceps brachii in the pretest and posttest of the experimental and control groups are presented in tables 1 and 2. The differences were analyzed with respect to the pretest. After practice, a significant increase of 30% was observed in MVC of elbow flexor muscles while the control group had 5.5% increase, and the changes in the strength of the experimental group significantly differed from the changes observed in the control group ($P \leq 0.05$).

Table 1. The results from the pretest and posttest of the experimental group

Variables	Pretest	Posttest
Strength (MVC)	9.173±1.96	11.961±1.453
Mean IEMG of Triceps Brachii	606±10.99	507.88±32.12
Mean IEMG of Elbow Flexor Muscles	603.37±10.88	762±23.12

Table 2. The results from the pretest and posttest of the control group

Variables	Pretest	Posttest
Strength (MVC)	10.256±1.45	10.785±1.635
Mean IEMG of Triceps Brachii	606±10.61	605±10.62
Mean IEMG of Elbow Flexor Muscles	601.87±5.55	603±5.28

The Figures 1 and 2 display the changes in the mean IEMG of elbow flexor muscles and triceps brachii in both the experimental and control groups. It can be seen in Figure 1 that there is no significant difference between the mean IEMG of elbow flexor muscles of the two groups in the pretest. Yet after practice, there is a significant difference between the two groups in this factor ($P \leq 0.05$) indicating that mental practice has led to a significant increase in IEMG after a practice period ($P \leq 0.05$); however, the IEMG changes in the control group increases inconsiderably during the protocol period which is not significant. As can be seen in Figure 2, there is no significant difference between the pretest of the control group and the experimental group in mean IEMG of triceps brachii, but a significant difference can be observed after practice ($P \leq 0.05$); IEMG decreased significantly in the experimental group, but the changes in the control group is not significant ($P \leq 0.05$). Further, based on Figure 3, the heart rate of the experimental group increased significantly in comparison with the resting heart rate ($P \leq 0.05$).

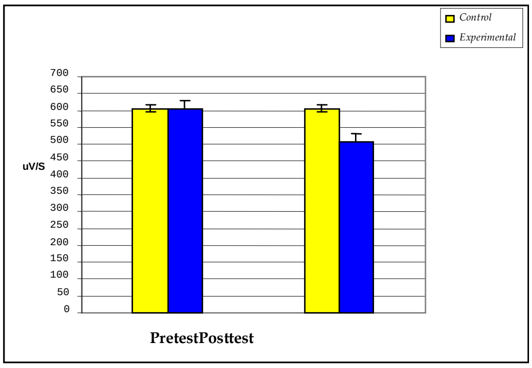

Figure 3. The mean changes in the IEMG of elbow flexor muscles in the control and experimental groups

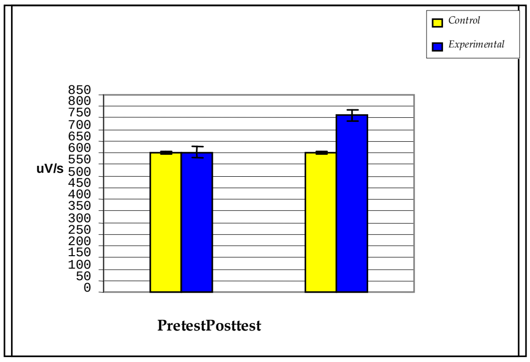

Figure 4. The mean changes in the IEMG of triceps brachii in the control and experimental groups

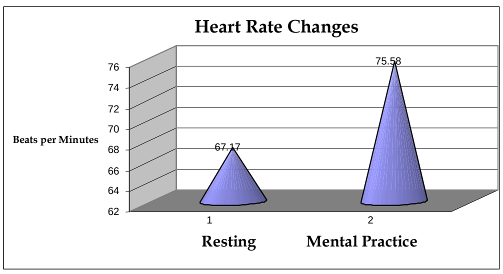

Figure 5. Changes in the resting heart rate and heart rate during mental practice

DISCUSSION

The key result of the present research was that mental practice increases the voluntary strength of elbow flexor muscles as well as their level of activation. The early strength gain mechanism as a result of mental practice is probably due to the changes in the commands of the central nervous system to the muscle [22]. Research studies suggest that by repeated mental attempts for maximum muscle activation, the brain will be activated for creating stronger signals and as a result, a stronger command in the central nervous system may employ the inactive motor units or to fire the active motor units more rapidly which will consequently lead to greater force production [14, 22]. Usually, activation of a muscle will stimulate motor units in a random, asynchronous fashion and this issue simply means that the actions of different motor units in a muscle are independent of one another; strength gain may be due to simultaneous recruitment of more motor units for a certain task which will facilitate contraction and increase the muscle's strength for force production. Moreover, the increase in the level of stimulation of motor neurons by the central nervous system will lead to increased stimulation frequency in the motor unit, and the change in stimulation frequency will change the force produced by the motor unit. In other words, increase in frequency will lead to an increase in the generated force [12, 19, 1]. If the electromyography of an agonist muscle is recorded during maximum voluntary contraction before and after the exercise program, the increase in EMG with regards to integrated electromyography indicates that more motor units have been recruited, or motor units are stimulated with more frequency, or that a combination of both has occurred [12]. Therefore, it seems that in the present research, the increase in IEMG or the level of activation of biceps brachii or brachioradialis following mental practice of maximum voluntary contractions is due to the increased coordination in recruiting the motor units as well as the increase their firing frequency.

Another neural adaptation due to practice could be the effect of learning. During an exercise performance, the task is new and the coordination between the related muscle groups – i.e. the primary agonist, fixator, and antagonist – may be less than desirable. But the coordination of the neuromuscular system gradually develops and performance is facilitated when these muscles are trained by performing the exercises [12, 1].The effect of learning on strength development was studied by Radford and Jones. These researchers reported that 12 weeks of weight training led to 150-200% increase in the lifted weight during the physical exercise of opening the legs. The reason for strength gain is mainly due to greater coordination between all the muscle groups involved in the movement. The improvement of coordination in a joint is a potential mechanism for strength gain at early stages of strength training. Thus, the neural adaptation created due to training may be due to the improved coordination of elbow muscles including the decreased activity of antagonist muscles while the agonist muscles are performing MVCs [1, 7]. In the present research, the IEMG of triceps brachii changed significantly (Figure 2) and thus the decreased activity of the triceps can play an important role in increasing strength. But the results of the present research are inconsistent with the results of Ranganathan with respect to the level of activation of triceps brachii. In the research of Ranganathan, the data of IEMG of triceps brachii did not change significantly after practice. It seems that in his research, the task was so easy to perform that all the subjects performed the task correctly [14]. But in the present research, the task or the test for measuring the strength of elbow flexor muscles was conducted under two different conditions (90° elbow flexion and 90° arm abduction) [20]. This movement probably requires a greater coordination between the agonist and antagonist muscles since only the elbow flexor muscles are involved. Thus, the activity of the antagonist muscle has decreased.
The results of the present research are inconsistent with the results of Herbert (1998) and Ranganathan (2004). In the present research, the changes in the strength of the experimental group were greater than the two previous studies. The strength changes of the groups differ significantly in the present research. In the research by Herbert, 1.8% strength gain was observed in the mental practice group and 1.5% strength gain was observed in the control group and in the

research by Ranganathan, the strength gain of the elbow flexor muscles was 13.5% in the experimental group and 4.8% in the control group. Yet in the present research, the strength gain of the elbow flexor muscles was around 30% in the mental practice group and 5.15% in the control group. In fact, mental practice has increased the strength of elbow flexor muscles more greatly in the research of 2004 than that of 1998, and in the present research the strength gain due to mental practice has been greater than that of the other two studies. In Herbert's research, it appears that the mental imagery used for subjects' mental practice has been of external imagery type [14]. The results of studies have shown that internal imagery is followed by increased physiological responses such as heart rate and blood pressure; that internal imagery is more efficient than external imagery and has a greater effect on performance [9]. In this regard, Ranganathan et al. (2000) showed that external imagery practice is not as efficient as internal imagery for strength gain [20]. In the present research, this factor was controlled by measuring the heart rate. Thus, Ranganathan (2004) used internal imagery (kinetic) which seems to be the reason for a greater strength gain in this research in comparison with the previous one. Another strong factor which affects imagery efficacy is one's mental imagery ability. Researchers showed that imagery is more effective when the individuals have greater imagery ability. Thus, it is not logical to expect a subject with poor imagery ability to be better than the subjects in the control group. In 1993, Morgan stated that imagery ability has a significant effect on imagery efficiency and a person who is unable to vividly imagine a motor skill is unlikely to benefit from the numerous advantages of mental practice [17, 6, 21]. In the present research, besides using internal imagery, the motor imagery ability of the subjects was measured using a revised Hall Questionnaire and subjects with medium-to-high imagery ability (subjects with a score of 16 or greater in imagery ability) were selected. Thus, the significant increase in the strength of the flexor muscles in comparison with previous studies can be attributed to controlling this very important factor. Moreover, the strength of the subjects in the control group increased by about 5.15% and this strength gain is probably due to the acquaintance of the subjects with the instructions and strength measurement devices which were equal for both groups.

It must be noted that psychological factor may lead to strength gain while measuring maximum voluntary contractions. Accordingly, in the pretest and during the measurement of the strength of elbow flexor muscles, all the subjects were cheered by the researcher for exerting more power and they were also notified that a prize is reserved for the subject with the highest record. This issue led to subjects' concentration on their performance during strength measurement and boosted their motivation which reduced the possibility of increasing the efforts in posttest measurements. Further, since the criterion for strength gain was the posttest data, it was very important for the subjects to have high motivation for applying the best attempts. Therefore, the subjects were encouraged to apply maximum force in the posttest same as the pretest [22]. Because the subjects practiced separately under the researcher's supervision, the researcher closely monitored the subjects for any clear, voluntary activation of the arm muscles during practice performance. Moreover, the subjects were repeatedly asked not to participate in any exercise program such as endurance training or strenuous aerobic exercise and not to perform physical activities beyond a normal level (relatively moderate). They were also asked to report any sudden change in their lifestyles or activity patterns as well as their job applications. All the subjects reported that their average daily activity had not changed and that they had not participated in any training program. In particular, they reported that they never exercised their elbow flexor muscles voluntarily. Since preliminary studies have shown that a low-intensity training program (less than 60% V02max)will not result in significant strength improvement, even if the participants had experienced instability in their daily activities during the research period, it seems unlikely that such instabilities would be close to 60% in the muscles of interest [4]. According to previous research, muscle hypertrophy can have a significant effect on muscle strength. But intense and repeated activation of muscles are required for muscle hypertrophy and in some studies it has been reported that even 20 near maximal strength training sessions has not led to muscle hypertrophy [6 & 18]; thus the issue of the effect of muscle hypertrophy on the strength of elbow flexor muscles in the present research is out of the question.

The results of the present research is consistent with the results of Yue, Smith, and Guang who first trained the abductor muscle of the little finger [16, 23] and the results are also consistent with the results of the research of Sideway. People rarely use the abductor of their little finger; in other words, this muscle is less contracted in daily activities. While the elbow flexor muscles are more widely used in daily activities and the elbow flexor muscles are used in almost all the activities that involve the forearm. Although the abductor muscle of the little finger and the elbow flexor muscles related to each of the groups are different, the abductor muscle of the little finger is a distal muscle and differs in cortical representation and monosynaptic cortico spinal projection from elbow flexors (proximal muscles) which are not involved in controlling the fine movements of the finger[4]; it seems that the present research managed to achieve similar results due to controlling the factors that affect the success of mental practice as well as placing greater focus on the mental practice dimension.

CONCLUSION

The increase in voluntary strength through mental practice and explication of the strength gain mechanism are important steps toward studying mental practice in the domain of neuropsychology and studying the neural mechanisms for voluntary strength gain and the results of the present research showed that the mind has a considerably greater ability than body and its muscles. Thus, people with high imagery ability can increase the strength of elbow flexor muscles through internal imagery. The present research makes us aware of the advantages of mental practice. It was shown in the present research that there are some advantages to mental practice that can be utilized for strengthening an immobile limb that has been secured due to harm, dislocation, or sports injuries. This issue has clear clinical and rehabilitative applications and is beneficial for those with fractures or serious injuries in their elbow and those who require securing their injured limb for a long-term period. Using this method minimizes the difficulties due to lack of exercise in the injured limb at the end of the exercise period and can be used as a rehabilitation technique.

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